serve a mix of diesel, gasoline, and alternative fuel vehicles. Table 6 shows the cost estimates for converting a 160-bus facility with 84,850 square feet of indoor storage, 19,250 square feet for the maintenance area, and a 9,120-square-foot fueling area.

At this time, CNG and LNG facilities have the highest capital costs.

Each alternative fuel facility must be custom designed to meet the specific needs of the transit agency. The cost of the facility can vary significantly. The cost estimates presented above should be viewed as representative figures for typical facilities. Consult Architect and Engineering firms experienced in alternative fuels for cost estimates for your particular site.

Emissions

With funding from DOE, West Virginia University's Department of Mechanical and Aerospace Engineering designed and constructed a transportable chassis dynamometer to test emissions levels from heavy-duty vehicles. The portability of this chassis dynamometer allows a large number of on-site emissions tests to be performed on buses and heavy-duty vehicles around the country. Before the unit was built, other options were considered, such as transporting vehicles to existing stationary dynamometers, or removing engines and transporting them to existing facilities. Both options were rejected because of expense and vehicle downtime.

The university has available a detailed description of the test procedures and the facility design.

Table 5. Refueling Facilities for a Fleet of 80 to 160 Alternative Fuel Buses

Alternative Fuel	Inventory Storage Options	Range of Incremental Capital Cost	Operating Cost	Comments
Diesel* (Baseline)	Underground Tank	Baseline	Low	Tank insurance would be needed.**
LNG	Above-ground Tank	$750,000 to $900,000	Low	
CNG (Fast-Fill)	Small High Pressure Accumulator Tank & Buffer	$750,000 to $1,500,000	Low to Medium	Compressors would require noise suppression.
CNG (Slow-Fill)	No Storage Needed	$600,000 to $900,000	Low	Noise suppression measures required for night operation.
Ethanol*	Underground Tank	$50,000 to $100,000	Low	Tank insurance would be needed.**
Methanol* (M100 or M95)	Underground Tank	$50,000 to $100,000	Low	Tank insurance would be needed.**
Biodiesel Blend*	Underground Tank	$0	Low	Tank insurance would be needed.**
Propane	Above-ground Tank	$100,000 to $150,000	Low	Fire suppression system required.

* Mobile fueling could be used, which eliminates capital costs, inventory costs, insurance costs, and is generally allowed by current codes/regulations.

** Tank insurance is insurance that covers fuel spills from the tank.

Table 6. Incremental Facility Costs for a Fleet of 160 Alternative Fuel Buses

(In millions of 1994 $)

	LNG	CNG	Alcohols*	Biodiesel	Propane
Fueling Facility	$0.90	$1.50	$0.10	N/C	$0.15
Maintenance Facility	$1.17	$1.08	N/C	N/C	N/C**
Bus Storage Facility	$1.44	$1.17	N/C	N/C	N/C**
Total	$3.51	$3.75	$0.10	N/C	$0.15

N/C = No change if facility is certified for gasoline

* Methanol and ethanol

**See Note 1 of Table 4.

Source: Battelle

Typically, the transportable chassis dynamometer is set up on the grounds of the test fleet or local transit agency and the selected heavy-duty trucks or buses are tested using the fuel in the vehicle at the time of the test. The dynamometer may be set up to operate inside or outside depending on the space available at the transit agency. To test the transit buses in the test program, WVU personnel used the standard Central Business District (CBD) test cycle, a driving cycle devised to simulate the speeds, loads, and conditions experienced by buses during a typical route through a city's central business district.

Results from WVU's testing show very high variability in emissions levels from the alternative fuel vehicles. Comparing emissions levels between heavy-duty vehicle technologies is a complex and evolving matter. Both engine certification and chassis dynamometer tests have shown that alternative fuels have a potential for substantially reducing emissions levels, but emissions are also highly dependent on the level of engine technology and the condition of the vehicle. Although NREL and WVU are attempting to select the latest technologies available, many of the vehicles tested over the past several years represent early versions of alternative fuel engines that were put on the road as part of a demonstration, or to assist in the development of the technology. Each manufacturer has updated its designs based on results from these demonstrations. Test results from the most recent offerings of both CNG and alcohol fueled engines suggest that emissions can be reduced significantly.

In early testing, some of the alternative fuel buses exhibited high levels of hydrocarbon (HC) and carbon monoxide (CO) emissions. In cooperation with the engine manufacturers, WVU discovered that many of these vehicles were either improperly tuned, or had problems with injectors, catalytic converters, or mixing valves. Recently, dramatic reductions in HC and CO emissions were achieved on a CNG bus in Miami after the catalytic converter and mixing valve were replaced.

WVU's emission testing has brought to light two very important points. First, by participating in demonstration programs, the transit agencies have played an important role in developing technologies that will help improve air quality. Second, alternative fuels play an important role in emissions reduction, but engine technology development and proper vehicle maintenance are also crucial factors.

A summary of the results from emissions tests performed in 1994 on 15 CNG, 10 methanol, 8 ethanol, 5 biodiesel, along with diesel control buses for each fuel type, is provided below.

Compressed Natural Gas

Most of the CNG buses tested so far have been early versions of the Cummins L10 engine that were not certified by the Environmental Protection Agency. Cummins has since made several improvements to enhance the performance of its engines, and to reduce their emissions levels. The California Air Resources Board has certified the later versions of this engine. Several L10 engines in New York City buses were upgraded to the certified configuration and tested late in 1994.

Figure 7 shows frequency distributions of the results from the CNG and diesel control buses tested by WVU. The height of the bar on the distribution diagram indicates the number of tests for which the emissions results were within the range of values shown on the x-axis. This figure shows that the particulate matter (PM) emission levels from the CNG vehicles were much lower than any of the diesel control vehicles. The CNG vehicles tested exhibited similar oxides of nitrogen (NO_X) levels to diesel controls. A significant number of vehicles tested on CNG exhibit lower CO emissions than do the diesel buses, but there were also a significant number of CNG buses with high CO levels. All of the buses exhibiting high CO levels were early uncertified versions of the L10 engine. All 6 buses with upgraded L10 engines had CO levels less than 1 gram per mile. Finally, the CNG buses tended to have higher total HC emission levels. The higher hydrocarbon emissions results are most likely due to methane emissions, which were not measured separately at the time of the tests. Because methane is considered to be non-reactive in forming ozone in the atmosphere, the Environmental Protection Agency has written the new regulations in terms of non-methane hydrocarbons. WVU plans

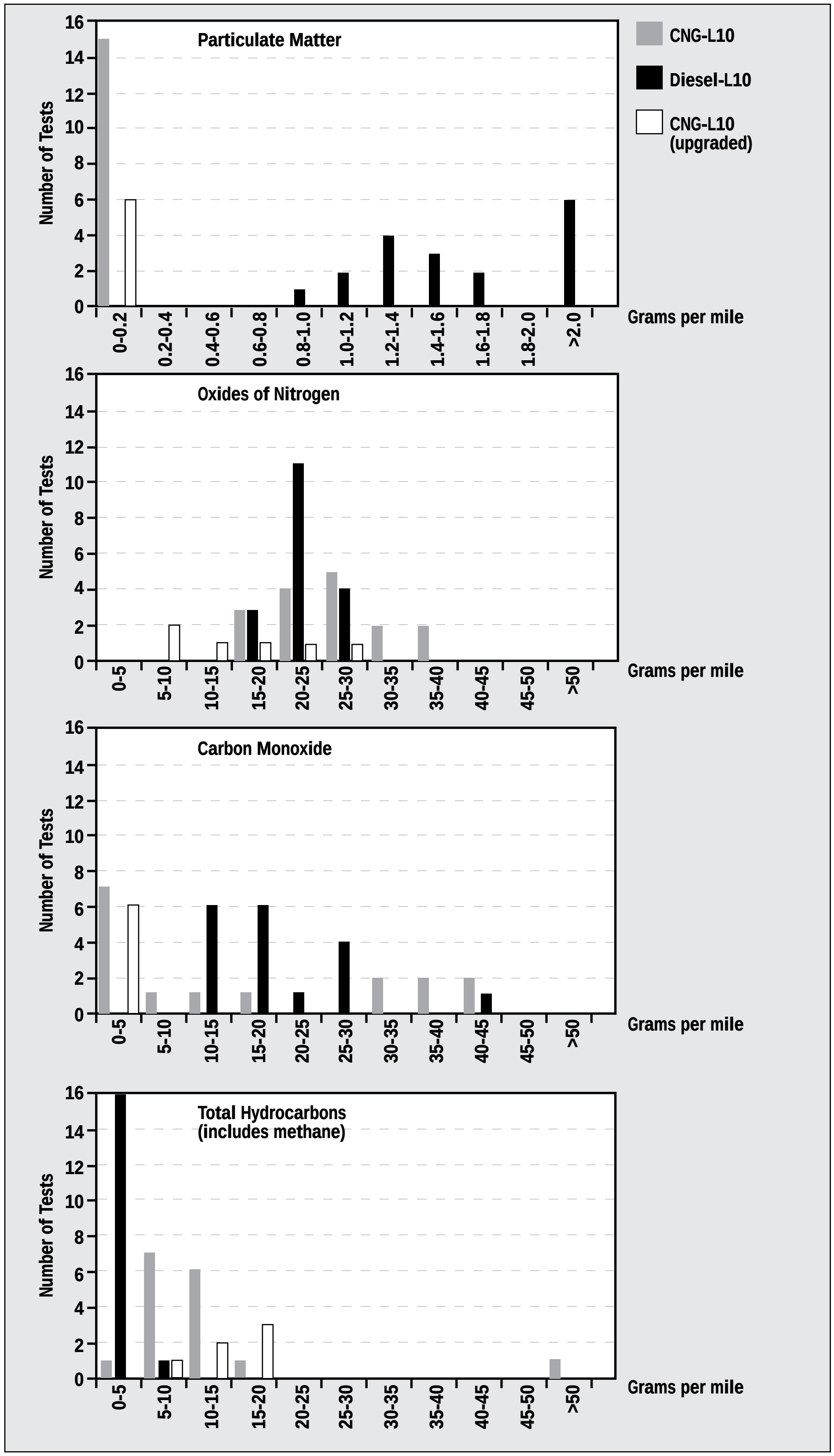

Figure 7. Frequency distribution of emissions from CNG and diesel buses

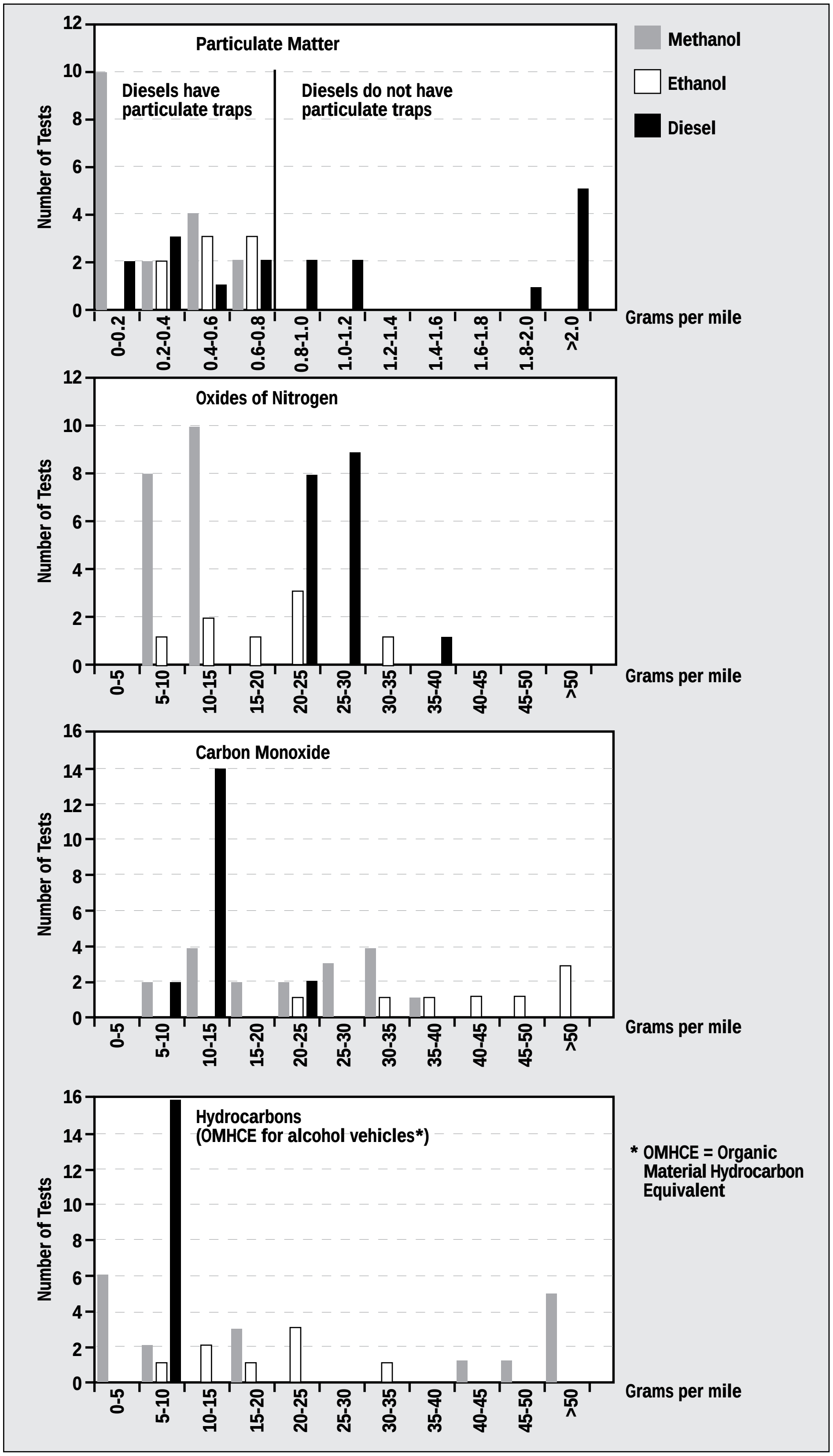

Figure 8. Frequency distribution of emissions from alcohol and diesel buses

to incorporate methane analyzers in future testing.

Alcohols

The results of chassis dynamometer emissions tests on ethanol and methanol buses powered by DDC 6V92TA engines are shown in Figure 8. The results from the alcohol buses are quite variable from site to site and bus to bus. Nonetheless, we can make some general observations. In general, the buses tested on ethanol and methanol appear to emit PM levels similar to diesel buses equipped with particulate traps, and significantly less PM than diesel buses without traps. Both ethanol and methanol buses emitted significantly lower levels of NO_X than did the diesel controls. The ethanol and methanol buses emitted significantly higher amounts of HC and CO. Note, however, that the HC data for the alcohol fueled buses are reported as organic material hydrocarbon equivalent, which includes a fraction of the unburned alcohol and aldehydes measured. Several newer methanol buses with DDC 6V92TA engines were tested in New York City late in 1994. These buses exhibited lower CO and HC levels than either the diesel or the older alcohol fueled buses.

Engine certification data from the DDC 6V92TA has shown emissions reductions in all four components (HC, CO, NO_X, and PM). We are investigating possible causes (including catalytic converters) for the increased HC and CO emissions levels from the test buses. Detroit Diesel Corporation has made recent improvements to the fuel injectors, which also may help to improve emissions levels.

Biodiesel

Figure 9 shows the results from the first round of chassis dynamometer tests on five DDC 6V92TA-powered buses run on biodiesel and five run on conventional diesel. The fuel used in the biodiesel buses was a mix of 20% soy biodiesel and 80% conventional diesel fuel. In the initial round of tests, the buses using the biodiesel fuel showed average reductions in CO, total HC, and NO_x emissions compared to the diesel buses, but the results were mixed from vehicle to vehicle. The differences seen so far are not statistically significant. The average particulate matter emissions seen in this testing was about the same for both diesel and biodiesel buses. Further testing will be conducted, and we will add a second biodiesel site to the program to determine the impact of biodiesel on emissions.

Other Considerations

All of the alternative fuels except biodiesel add to the curb weight of the bus. Table 7 shows the approximate increase in curb weight of a 40-foot bus as a result of the alternative fuel option.

CNG has the greatest weight penalty because of the weight of the tanks. As tank technology advances, we expect some decrease in this penalty.

Most municipal, state, and federal highways have restrictions on the axle loading that is allowed, to prevent excessive damage to the

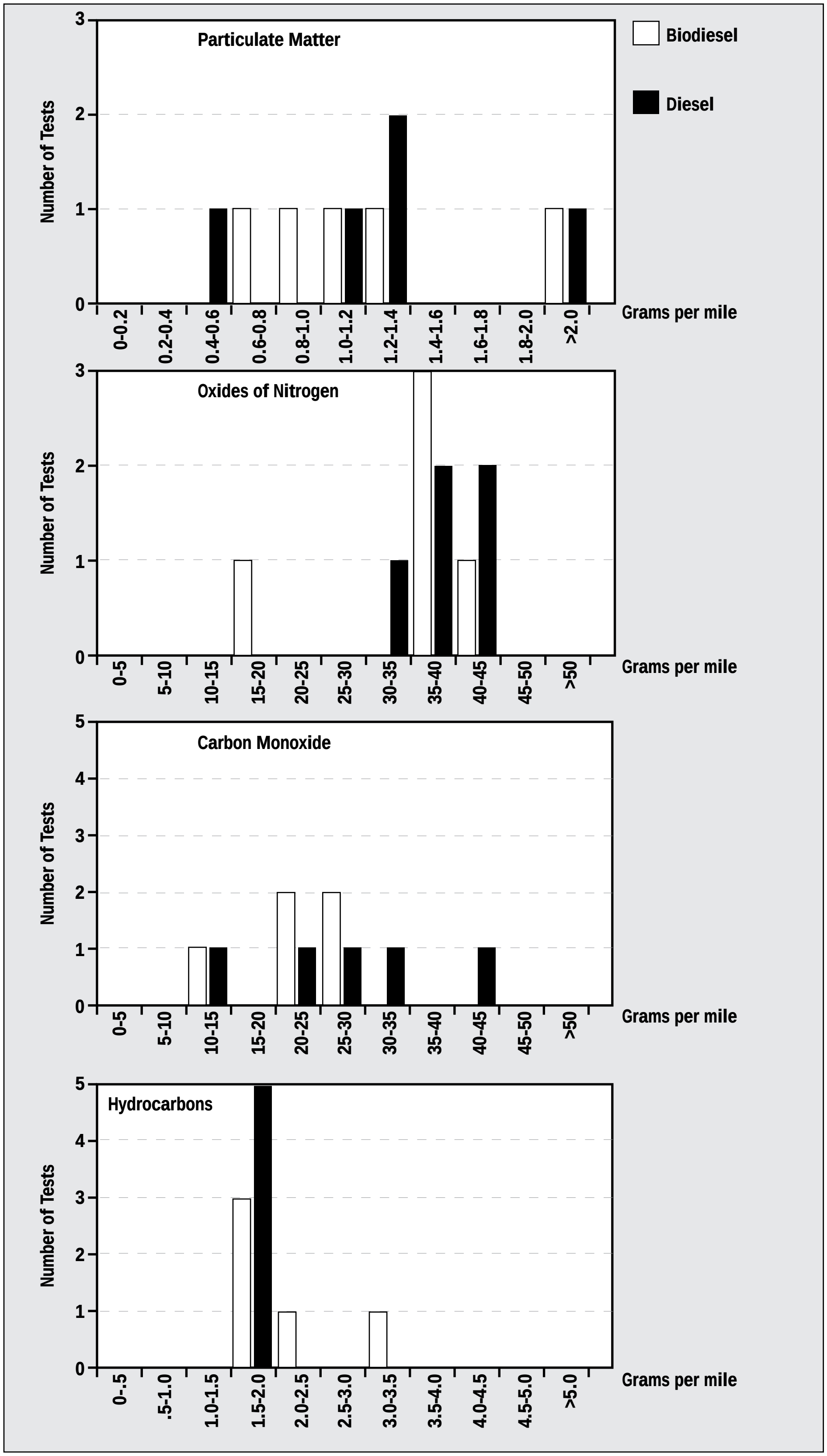

Figure 9. Frequency distribution of emissions from biodiesel and diesel buses